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THESIS

AN EVALUATION OF B-ISDN FOR THE COMMUNICATION ARCHITECTURE REQUIREMENTS OF DISTRIBUTED INTERACTIVE SIMULATION (DIS)

by

Christopher V. Arias, Lieutenant, USN

March, 1994

Thesis Co-Advisors: Dr. Carl R. Jones
Dr. Myung W. Suh

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Distributive Interactive Simulation (DIS) requires a communication architecture to support large scale simulations (100,000 entities). The communication architecture requirements for DIS are now being defined. DIS will require a wide area network that supports high data rates, multicasting and low latency. DoD can no longer afford unique solutions for their wide area networking needs and must align their service requirements with the services provided by common carriers. An analysis is presented on how the future Broadband Integrated Services Digital Network (B-ISDN) and its technology standard, Asynchronous Transfer Mode (ATM), could help meet the WAN communication architecture requirements of DIS. The requirements of DIS are presented and mapped into a format compatible with international standards for common carrier services. Quality of Service (QoS) parameter values for DIS information types are estimated and compared to those of B-ISDN. Conclusions reveal that B-ISDN and its underlying technology, ATM, will help meet the DIS WAN communication architecture needs. Also, QoS parameter values for DIS require further definition and specificity to enable DoD to take advantage of the future common carrier services. DoD needs to define its future application requirements to enable the use of future public communication networks. The method presented can be used to define existing and future application requirements that are compatible with common carrier services.

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by

Christopher V. Arias
Lieutenant, United States Navy
BSCS, United States Naval Academy, 1987

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March, 1994

Author: ______________________
Christopher V Arias

Approved By: ______________________
Carl R. Jones, Thesis Co-Advisor

____
Myung W. Suh, Thesis Co-Advisor

____
David R. Whipple, Chairman,
Department of Systems Management

ABSTRACT

Distributive Interactive Simulation (DIS) requires a communication architecture to support large scale simulations (100,000 entities). The communication architecture requirements for DIS are now being defined. DIS will require a wide area network that supports high data rates, multicasting and low latency. DoD can no longer afford unique solutions for their wide area networking needs and must align their service requirements with the services provided by common carriers. An analysis is presented on how the future Broadband Integrated Services Digital Network (B-ISDN) and its technology standard, Asynchronous Transfer Mode (ATM), could help meet the WAN communication architecture requirements of DIS. The requirements of DIS are presented and mapped into a format compatible with international standards for common carrier services. Quality of Service (QoS) parameter values for DIS information types are estimated and compared to those of B-ISDN. Conclusions reveal that B-ISDN and its underlying technology, ATM, will help meet the DIS WAN communication architecture needs. Also, QoS parameter values for DIS require further definition and specificity to enable DoD to take advantage of the future common carrier services. DoD needs to define its future application requirements to enable the use of future public communication networks. The method presented can be used to define existing and future application requirements that are compatible with common carrier services.

TABLE OF CONTENTS

I. INTRODUCTION

A. PURPOSE OF THESIS

The purpose of this thesis is to present an analysis of the Broadband Integrated Services Digital Network (B-ISDN) as a wide area network communication architecture for the Distributed Interactive Simulation (DIS). Unprecedented transformations in the world of telecommunications have made high quality, high speed transmission, multiplexing and switching communications services of B-ISDN a realistic candidate for DoD wide area network needs. These transformations are based on the Asynchronous Transfer Mode (ATM) technology.

As DoD plans its future enterprise network, it must realize the importance of high speed networking to meet all existing and future service requirements. One future service requirement is Distributive Interactive Simulation (DIS).

Increasing domestic budgetary pressure necessitates a shift from large, real forces training exercises to real time training simulations available through a synthetic battlefield. DoD has labeled the synthetic environment a major science and technological thrust. [ISTB93:p. 23] DIS promises to provide the capability of large, real time simulations.

These simulations will require a wide area network (WAN) communication architecture to transport the information from remote simulations sites. DoD cannot afford a private network to connect these sites and must align its service requirements to the public network services.

The author provides an analysis of a future common carrier service, B-ISDN, and determines its suitability for the Distributed Interactive Simulation (DIS) communication architecture requirements.

B. SCOPE OF THESIS

The main focus of this thesis is how B-ISDN could help meet a specific DoD service's requirements. Asynchronous Transfer Mode (ATM) is the technology standard on which B-ISDN is based. In order to understand B-ISDN and its services, ATM fundamentals will be discussed. Then the performance characteristics of ATM will be examined followed by a discussion of future B-ISDN services[1]. To examine the suitability of B-ISDN for Distributive Interactive Simulation (DIS) networking needs, the DIS communication architecture requirements will be discussed and mapped into a format compatible with CCITT standards for developing and standardizing common carrier services. Finally an analysis of B-ISDN to meet these requirements is presented. The discussion is limited to the wide area network portion of the communication architecture. The complete communication architecture would include local area networks at the simulation sites which are connected to a wide area network.

Along with the documented DIS requirements, the major issue of the communication architecture's Quality of Service (QoS) requirements will be addressed. The author estimates the QoS parameters values and evaluates B-ISDN's suitability to meet these requirements.

C. BACKGROUND

1. Global Grid

Global Grid is a DoD communication concept designed to aggressively pursue worldwide distribution and processing of data and employ distributed resources such as databases, high performance computers and multi-media communications [NRL94:p. 5]. Global Grid will ride on local area networks (LANs), metropolitan area networks (MANs), and wide area networks (WANs) in an internetworked communication architecture. Global

1. Due to the early stage of development of B-ISDN and ATM, only the fundamental performance characteristics of a generic ATM network will be provided.

Grid will involve both public and private networks. The Global Grid movement is a result of the explosion of telecommunications technology in several dimensions:

- Data Rates
- Connectivity
- New Services
- World Standards

[NRL94:p. 10]

Global Grid consists of several subcategories that describe the capabilities envisioned by this concept. One of these capabilities is Advanced Distributive Simulation (ADS).

2. Advanced Distributed Simulation

Advanced Distributed Simulation (ADS) is a current movement in DoD to create large virtual worlds with real time simulation capabilities [ISTB93:p. vii]. These large virtual worlds will enable DoD to create synthetic environments for purposes such as synthetic battlefields. DoD has identified synthetic environments as a major science and technology thrust [ISTB93:p. 23]. The creation of synthetic environments promises the ability to:

- Train large scale forces in a realistic environment.
- Plan and rehearse operational missions.
- Develop new tactics and concepts of operation.
- Test and verify new systems early in development cycles.

[ISTB93:p. vii]

Between 1983 and 1989 the Advanced Research Projects Agency (ARPA), formerly the Defense Advanced Research Projects Agency (DARPA), created and demonstrated the ability to network large numbers of simulators. This project culminated in the creation of the Simulation Networking (SIMNET) R & D project. [ISTB93:p. 20] The largest distributed simulation exercise on SIMNET was WAREX 3-30 in which approximately 800-1000 objects (entities) from five different physical sites were simulated concurrently in real time. [Chung92:p. 173] The success of SIMNET has led ARPA to

envision a much larger battlefield simulation. This vision is the ADS movement [ISTB93:p. vii].

The goal of ADS is to provide the ability to conduct real time simulations of 10,000 entities by 1995 and 100,000 entitites by the year 2000. In 1990 DARPA sponsored a review of the technical approach used in SIMNET and the feasibility of this approach to meet these goals. The general consensus of the review board was that the current architecture of SIMNET could meet the 1995 goal, but the goal for year 2000 was questionable on the basis of several factors. One of these factors is the need for a standard infrastructure that will make heterogeneous simulations interoperable. [Chung92:p. 175]

These standards are required in the areas of interfacing, communication architecture, representation of the virtual environment, management, security and performance measurement. The standardization movement is known as Distributed Interactive Simulation (DIS). [ISTB93:p. vii]

3. Distributed Interactive Simulation (DIS)

> The primary mission of DIS is to define an infrastructure for linking simulations of various types at multiple locations to create realistic, complex, virtual worlds for the simulation of highly interactive activities. [ISTB93:p. 1]

In a DIS environment a large number of manned and semi-automated vehicle simulators are networked together. Simulators are connected by local area networks (LANs) within a site and by a wide area network (WAN) between sites. The world consists of entities. These entities represent the players in the simulation or simulations. These entities can be live crews in real vehicles, constructive automated wargames, or virtual simulators [Chung92:p. 171]. Entities communicate via a communication architecture by means of protocol data units (PDUs). The PDUs do not define what the simulator or site is but only define the way it communicates with the outside world [ISTA93:p. 1].

The communication architecture defines how the simulators, simulation sites, and other DIS entities can be connected. The DIS standard for the communication

architecture is known as the Communication Architecture for Distributive Interactive Simulation (CADIS) [ISTA93:p. 2].

4. Communication Architecture

The communication architecture represents one of the several standards of the DIS movement. Currently the standard is defined in a for comment draft that provides the rational for the key issues of the architecture. The communication architecture to meet the requirements of the DIS will be heavily dependent on the communication industry's WAN services [ISTA93:p. 5]. Internetworking is an important aspect of large scale simulations because it provides the ability to:

- Use commercial services as opposed to private networks.
- Use different local network topologies and technologies.

[Macedonia93:p. 5]

a. Standards

CADIS [ISTA93] represents a for comment draft on the standardization and discussion of the communication architecture requirements to support the future needs/ goals of ADS. The draft document states the need for the communication architecture to support multicasting, meet bandwidth requirements, latency requirements and error requirements. Work on standardization of the communication architecture is in the areas of:

- Addressing
- Reliability
- Protocols
- Bandwidth
- Constraints on PDU size

[ISTB93:p. 3]

Other research is being accomplished in the areas of requirements in terms of scalability and interfaces for the various types of simulator participants (entities).[Chung92]

D. OUTLINE OF CHAPTERS

In Chapter II, ATM Fundamentals, the general fundamentals of Asynchronous Transfer Mode (ATM) are discussed. The issue of standardization is presented due to its importance for the acceptance and success of ATM and B-ISDN services. Only those fundamentals related to specific performance characteristics described in Chapter III are provided.

In Chapter III, ATM Performance Characteristics and Services, general communication network performance characteristics are discussed and general ATM performance parameter values are presented. It should be noted that only specific performance values for ATM networks are available; the standard performance characteristics of B-ISDN are not yet available. B-ISDN services are also provided.

In Chapter IV, DIS Communication Architecture Requirements, the DIS communication architecture (CADIS) requirements are discussed. The requirements of the CADIS document [ISTA93] are presented and additional discussion is given for the requirements of bandwidth and multicasting.

In Chapter V, B-ISDN Evaluation, the B-ISDN services are evaluated. The requirements of Chapter IV. are mapped into a format compatible with CCITT standards. The QoS service requirements of DIS are estimated in an attempt to define some characteristic values with which B-ISDN may be evaluated.

The last chapter will provide the summary and concluding remarks.

II. ATM FUNDAMENTALS

A. INTRODUCTION

1. Purpose of this Chapter

The purpose of this chapter is to provide a general overview of the fundamentals of Asynchronous Transfer Mode (ATM). ATM is in the 'childhood' stage of development and implementation. Many technical issues have been left for further study and work on standards is still in progress. ATM development and implementation is being accomplished by several interest groups. Industry, standards organizations, and end users are working to bring ATM to use and solve interoperability issues quickly. The fundamentals described in this chapter represent a broad view of the technology to give an understanding of what ATM is, why ATM meets certain performance characteristics to be discussed in Chapter III and how ATM, as the technology building block of B-ISDN, could help meet the DIS performance requirements.

2. Transfer Mode Overview

The term transfer mode is used by standards organizations to describe the technique used by a telecommunication network to switch, multiplex and transmit data [Depr93:p. 50]. A review of the most prominent types of transfer modes is beneficial in understanding ATM's evolution as a communication technology.

a. Circuit Switching

Circuit switching is the transfer mode long used in the telephone networks and is oriented toward analog voice communications. It is connection oriented and offers low and nonvariable delay by avoiding complex routing, flow and error control [Stal92:p. 28]. The multiplexing technique used is Time Division Multiplexing (TDM) also known as Synchronous Transfer Mode (STM) and switching is performed by space or time switching

or a combination of both [DePry93:p. 50]. As a transfer mode oriented toward analog voice communications, circuit switching has limited functionality and flexibility for digital data transfer.

b. Packet Switching

Packet switching evolved as a transfer mode due to demand for a more functional and flexible transfer of data communications around 1970. Packet switching divides data into segments which are then wrapped in an envelope to form a packet. Each packet contains the user information and some header information essential for the movement through the network. [Stal92:p. 72] Packet switching was designed when the quality of the transmission media was poor and thus complex protocols were required to ensure end to end performance [Depry93:p. 56]. Because of this error and flow control on a link to link basis, packet switching induces additional processing and switching delay and is not suitable for real time services such as video. However, packet switching is a reliable and efficient transfer mode for low data rates (<64kbps). [Depry93:p. 56]

c. Frame Relay

Frame relay is a recently introduced fast packet switching transfer mode that addresses the need for higher digital data communication rates to handle real time services and lower data rate services in one network. Like packet switching it uses variable length data units. Due to an increase in the reliability of transmission media, frame relay does not require error and flow control on a link to link basis. [Maz93:p. 55/5] Frame relay is suited for LAN to LAN traffic and offers standard rates of 56kbps, n x 64 kbps, and 1.544 Mbps [Min93:p. 580].

d. Cell Relay

Cell relay, like frame relay, is a fast packet switching technique that requires minimum functionality in the network, i.e., there is no error protection or flow control on a link to link basis [Depry93:p. 58]. Cell relay is connection oriented and uses short, fixed

length packets, called cells, and uses hardware based switching techniques to achieve high throughput and low delays. Cell relay can be used to transmit all types of information, including voice, data, video, and signalling [Maz93:p. 55/7]. The international standard for cell relay is Asynchronous Transfer Mode (ATM).

B. ATM STANDARDS

As a new technology, most of the work in ATM has been oriented toward standardization. Most of the standardization was completed in 1991 [Kor92:p. 32]. Standardization is essential to the success of a new technology as it allows industry and end users to define the nominal specifications for interoperability. ATM has been recommended as the standard transfer mode for the Broadband Integrated Services Digital Network (B-ISDN). Standards work for B-ISDN is being accomplished by traditional standards organizations and by an industry forum. The industry forum brings a diverse spectrum of industrial and end user players to rapidly build consensus on commercial interests and details of interoperability. Figure 1 illustrates the United States organization for developing B-IDSN standards. [Amy94:p. 53]

1. CCITT and ANSI

The State Department represents the United States in the international standards organization International Telecommunications Union-Telecommunications Standardization Section (ITU-T), formerly the Consultative Committee for Telephone and Telegraph (CCITT). In the United States the American National Standards Institute (ANSI) technical subcommittees T1A1, T1E1, T1M1, and T1S1, have the responsibility for technical review of B-ISDN documents prior to submission to ITU-T. [Amy94:p. 54]

These ANSI technical subcommittees concentrate on proper standardization of ATM for the future B-ISDN network and their work mainly reflects the view of network operators and national administrators [Depry93:p. 103]. Table 1 lists the June 1992 ITU-T (then CCITT) recommendations [Stal93:p. 526].

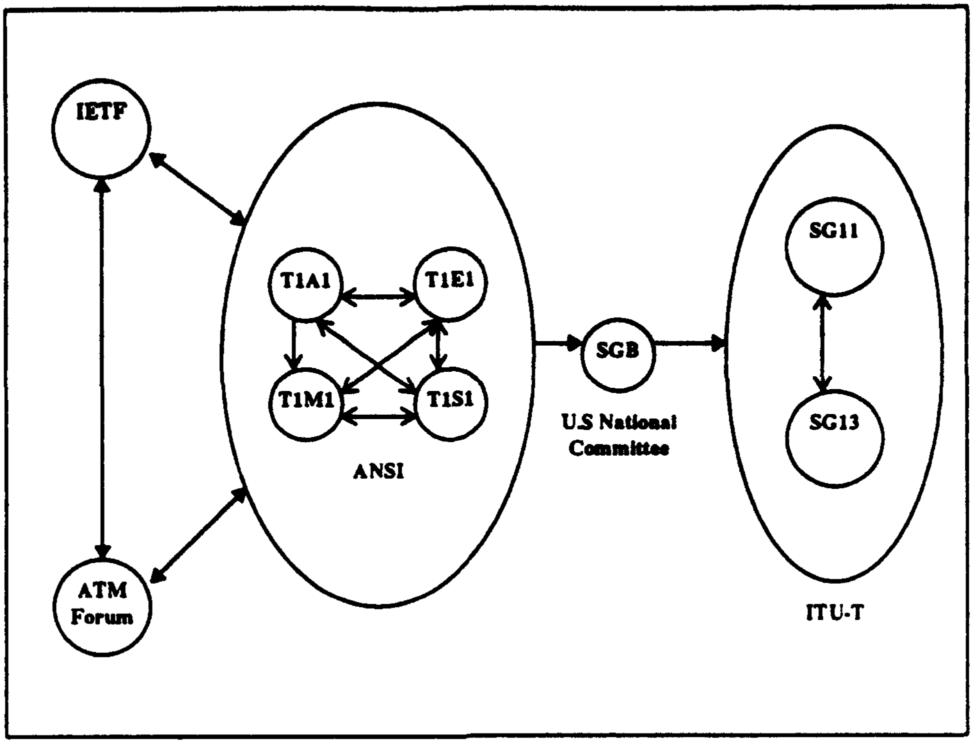

Figure 1: B-ISDN Standards Organization

TABLE 1: B-ISDN RECOMMENDATIONS

I.113 Vocabulary of Terms for Broadband Aspects of ISDN
I.121 Broadband Aspects of ISDN
I.150 B-ISDN ATM Functional Characteristics
I.211 B-ISDN Service Aspects
I.311 B-ISDN General Network Aspects
I.321 B-ISDN Protocol Reference Model and its Application
I.327 B-ISDN Network Functional Architecture
I.361 B-ISDNB-ISDN ATM Layer specification
I.362 B-ISDN ATM Adaptation Layer (AAL) Functional Description
I.363 B-ISDN ATM Adaptation Layer (AAL) Specification
I.364 Support of broadband connectionless data service on B-ISDN
I.371 Traffic and congestion control in B-ISDN
I.413 B-ISDN User-Network Interface
I.414 Overview of Recommendations on layer 1 for ISDN and B-ISDN customer accesses
I.432 B-ISDN User-Network Interface - Physical Layer Specification
I.610 OAM Principles of B-ISDN access

2. ATM Forum

Working with the traditional standards groups is an industry group called the Asynchronous Transfer Mode Forum. The ATM Forum was formed in September of 1991 and currently consists of over 400 organizations who have grouped to encourage and develop agreements on the details of ATM [Masn94:p. 52]. The National Security Agency (NSA) is the DoD representative on the ATM Forum.

Whereas the ITU-T reflects the public network interests, the ATM Forum represents the private, customer premises interest to facilitate interoperability and accelerate early availability of ATM networks [Amy94:p. 54]. In June of 1992, The ATM Forum produced specifications on the Private User-Network Interface, and the Public User-Network Interface. The ATM Forum will proceed with specifications in the areas of operation, signaling, the Network-Network Interface, congestion control, traffic management, new applications and adaption layers. [Depry93:p. 103]

3. Internet Engineering Task Force (IETF)

The Internet is generally expected to move toward the use of ATM. Consequently the Internet Engineering Task Force (IETF), which develops the Transport Control Protocol/Internet Protocol (TCP/IP), is active in the standards movement for ATM [Amy94:p. 54]. IETF is primarily concerned with how to send IP datagrams over ATM and is addressing other issues such as address resolution and routing [NRL93:p. 20].

C. ATM PROTOCOL

CCITT recommendation I.121, a guideline for B-ISDN standardization, delineates the organization of the ATM cell format. According to this recommendation information is organized into fixed cells each containing a header and an information field. The cell structure is further described below.

1. Cell Structure

The size of an ATM cell has been set at 53 octets, consisting of a 5 octet header and a 48 octet information field, by CCITT recommendation I.121 [Bae91:p. 182]. The header formats differ between a User -Network Interface (UNI) and a Network-Network Interface. Figure 2 illustrates the format of ATM cells for the UNI and NNI [Bae91:p. 182].

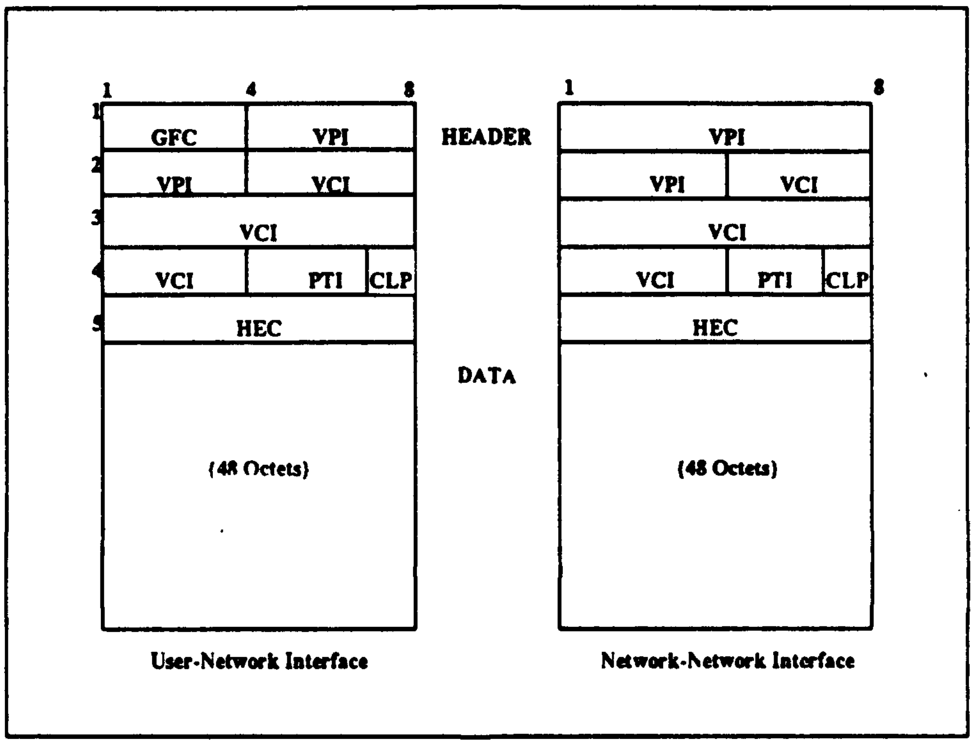

Figure 2: ATM Cell Format

The User-Network Interface header contains a 4 bit generic flow control field (GFC), a 24 bit label field containing the Virtual Path Identifier (VPI) and Virtual Circuit Identifier (VCI) subfields, a 3-bit payload type field (PTI), a 1-bit priority field (CLP), and an 8 bit header error control field (HEC). The Network-Network Interface header does not contain the GFC field and the VPI field is four bits longer. [Bae91:p. 182] The functions of these field are described below:

- General Flow Control (GFC): Used by the flow control mechanism at the UNI. Mechanisms are yet to be determined.
- Virtual Path Identifier (VPI): Used for directing cells within the ATM network (see discussion below).

- Virtual Channel Identifier (VCI): Used for directing cells within the ATM network (see discussion below).
- Payload Type: Identifies the type of data being carried by the cell.
- Cell Loss Priority (CLP): If this bit is set, the cell has low priority and is subject to being discarded when the network is under stress.
- Header Error Control (HEC): Generated and inserted by the physical layer. Serves as a checksum for the first 4 octets of the ATM header. It can correct single-bit errors and detect some multiple-bit errors.

[Cavan92:p. 3]

Compared to traditional packets of packet switching networks, the reduced length and functionality of the header reduces the processing at the ATM nodes and allows for lower processing and queuing delays. The reduced length of the information field reduces the number of internal buffers in switching nodes and limits the queuing delays in those buffers, thus guaranteeing a small delay [Depry93:p. 60]. The fixed length cell results in higher switching speeds and less queue memory size requirements in the switching nodes [Depry93:p. 79].

2. Transmission Structure

The ATM Forum specifies a SONET STS 3 interface for the public and private UNI interfaces to synchronous networks [Depry93:p. 118]. CCITT has recommended an interface based on Synchronous Digital Hierarchy (SDH) [Min93:p. 563]. SONET and SDH are practically compatible, with differences occurring in the use of overhead [Depry93:p. 118]. Figure 3 illustrates the transport of ATM cells on a SONET frame [Min93:p. 563]

A transmission structure based on the international standards of SONET and SDH establishes a hierarchy of transmission speeds for future data rate needs. As a standard for optical fiber transmission SONET and SDH bring the benefits of the bandwidth of fiber. The standard could support up to 9.6Gbps [Maz93:p. 53/26].

D. B-ISDN PROTOCOL REFERENCE MODEL

The B-ISDN Protocol Reference Model, as shown in Figure 4, is structured to reflect the Open Systems Interconnection (OSI) model [Maz93:p. 41/14].

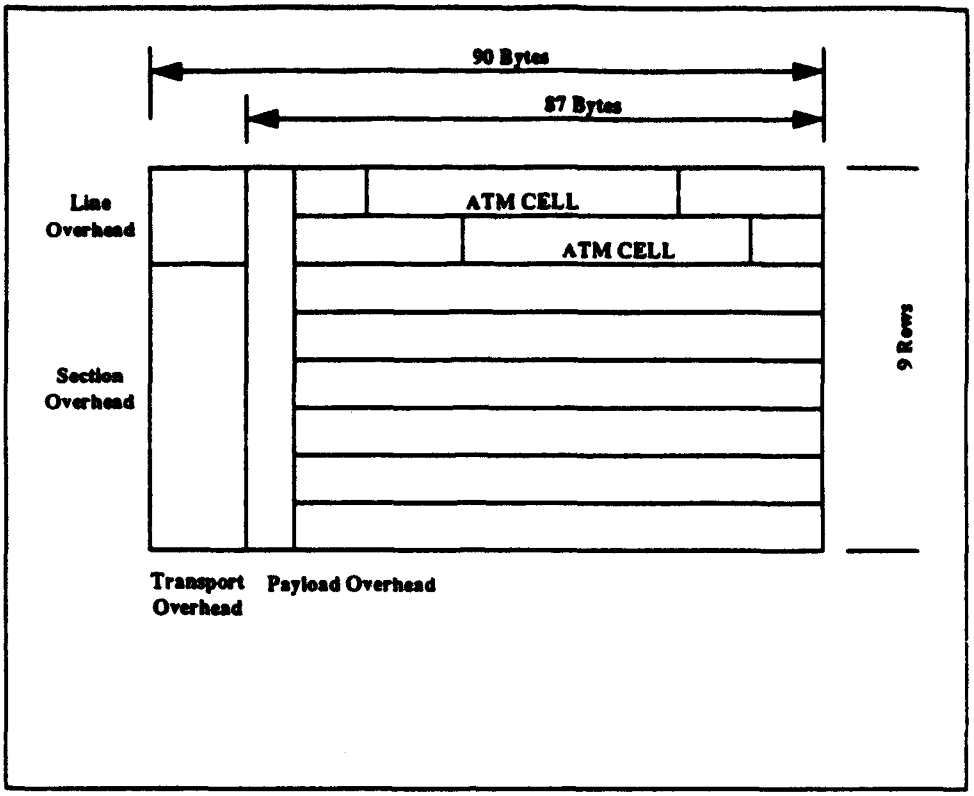

Figure 3: ATM Cell Transmission on SONET

The B-ISDN protocol reference model is based on CCITT Recommendation I.321. The model contains 3 planes: a user plane, a control plane and a management plane plus a further dimension called the plane management. For each plane, a layered approach is taken as in OSI. [Depry93:p. 112] The functions of the planes are:

- User Plane: Provides for user information transfer, along with associated flow and error controls.
- Control plane: Performs call-control and connection functions.
- Management Plane: Provides network supervision functions: Plane management and Layer Management.

[Min93:p. 546]

CCITT has further divided the B-ISDN layers into a number of sublayers as illustrated in Figure 5 [Min93:p. 548]. These subdivisions and their functions are further described below.

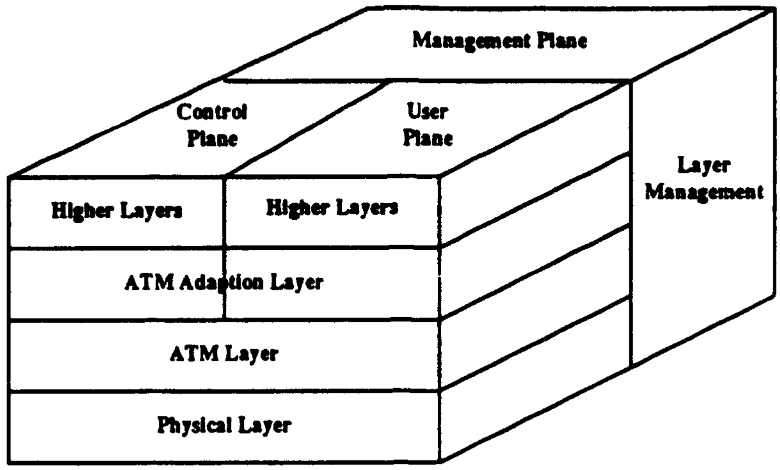

Figure 4: B-ISDN Protocol Reference Model

Signaling ATM Adaption Layer	ATM Adaption Layer	• Convergence (CS) • Segmentation and Reassembly
Asynchronous Transfer Mode Layer		• Generic Flow Control • Cell Header Generation • Cell VPI/VCI Translation • Cell Multiplexing/Demultiplexing
• Transmission Convergence		• Cell rate decoupling • HEC header sequence generation/ verification • Cell delineation • Transmission frame adaption • Transmission frame generation/recovery
• Physical Medium Dependent		• Bit Timing • Physical Medium

Figure 5: B-ISDN Layers and Sublayers

1. OSI and B-ISDN relationship.

The relationship between the OSI Protocol Reference Model and the B-ISDN Protocol Reference Model is important in the near term to allow for the internetworking of OSI based networks and B-ISDN based networks. Figure 6 illustrates this relationship [NRL93:p. 21].

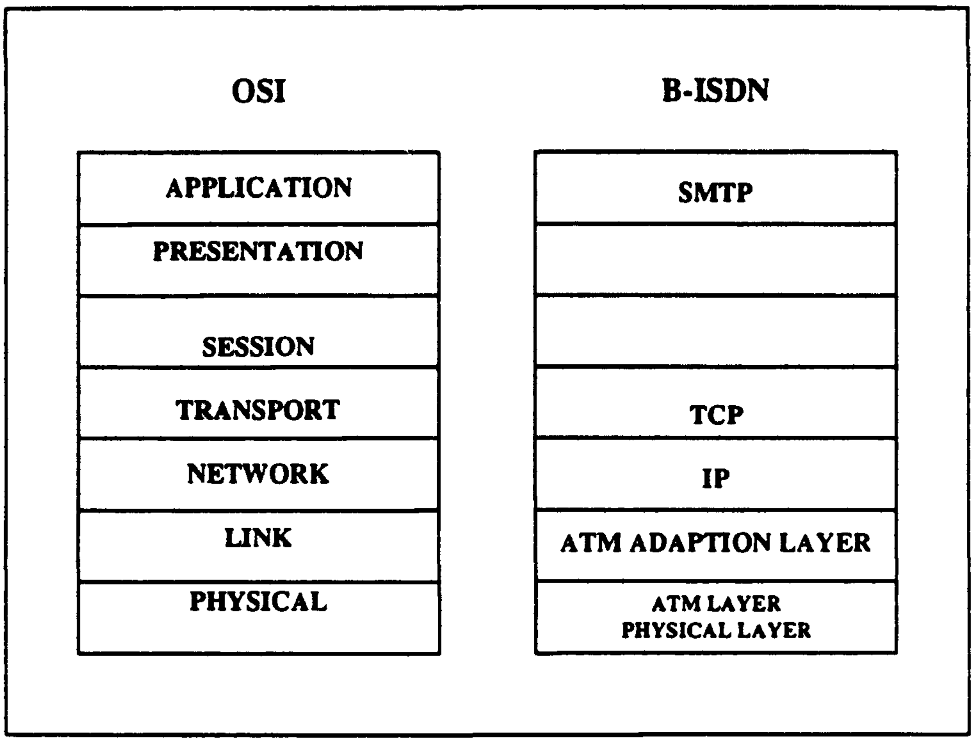

Figure 6: OSI and B-ISDN Protocol Reference Models

The ATM layer can be likened to the OSI physical layer with an elaborate multiplexing capability. The ATM Adaption Layer (AAL) can be likened to the Data Link layer. [Pes93:p. 15]

2. Physical Layer

The user plane physical layer is subdivided in two sublayers, the physical medium dependent sublayer and the transmission convergence sublayer [Min93:p. 547]. The physical layer is described by CCITT Recommendation I.432 for the User-Network

Interface and by the ATM Forum in the ATM User-Network Interface Specification [Depry93:p. 113].

a. Physical Medium Dependent

The Physical Medium Dependent (PMD) supports those functions dependent on the physical medium. It provides bit transmission capability, such as bit timing and electric-optical transformation. [Min93:p. 547]

b. Transmission Convergence

As shown in Figure 6, the Transmission Convergence layer performs five functions. These are:

- Transmission frame generation and recovery: Transmission at the physical layer consists of frames. This function is concerned with generating and maintaining the frame structure for a given data rate.
- Transmission frame adaption: Information exchange at the ATM layer is a flow of cells. The TC is responsible for packaging cells into a frame. Transmission frames may be a cell equivalent, an SDH envelope or a SONET envelope.
- Cell delineation: This sublayer is responsible for maintaining the cell boundaries so that the cells can be descrambled at the destination.
- HEC sequence generation and cell header verification: This sublayer is responsible for generating and checking the Header Error Control code.
- Cell rate decoupling: this includes insertion and suppression of idle cells in order to adapt the rate of valid ATM cells to the payload capacity of the transmission system.

[Stal92:p. 523]

3. ATM Layer

The ATM layer is independent of the physical medium that transports ATM cells [Pes93:p. 13]. The user plane ATM layer principal functions are:

- Cell multiplexing and demultiplexing: Multiple logical connections may be maintained across an interface
- Virtual path identifier (VPI) and Virtual channel identifier (VCI) translation: VPI and VCI logical connections may need to be translated during switching due to their local significance.
- Cell header generation/extraction: A cell header is appended to user data from the AAL. The ATM Layer generates all fields in the header except the Header Error Control (HEC) code.
- Generic flow control: Generates flow-control information for placement in cell headers.

[Stal92:p. 523]

4. ATM Adaption Layer

The role of the ATM Adaption Layer (AAL) is to enhance the ATM services provided by the ATM layer for specific classes of applications [Pes93:p. 13]. The AAL helps upper layer protocols adapt to using ATM. Some applications may require additional functionality on top of the ATM layer. These services can be user services, as well control or management functions. [Pes93:p. 13] These services are displayed in Table 2. [Maz93:p. 41/15]

TABLE 2: ATM SERVICE CLASSIFICATION

	Class A	Class B	Class C	Class D
Timing Relation between source and destination	Required	Required	Not Required	Not Required
Bit Rate	Constant	Variable	Variable	Variable
Connection Mode	Connection Oriented	Connection Oriented	Connection Oriented	Connection-Less

Examples of the four classes of services are given in Table 3. Services are classified by three parameters: the time relation between source and destination, constant or variable bit rate, and connection mode. [Maz93:p. 41/15]

TABLE 3: ATM SERVICE EXAMPLES

Class of Service	Example of Service
Class A	Circuit emulation
Class B	Variable bit rate video
Class C	Connection oriented data transfer

TABLE 3: ATM SERVICE EXAMPLES

Class of Service	Example of Service
Class D	Connectionless data data transfer

Three AAL protocols have been defined to support the four classes of service. AAL 1 supports Class A, AAL 2 supports Class B and AAL 3/4 supports Class C and D. Each type of AAL is subdivided in two sublayers: the segmentation and reassembly (SAR) sublayer and the convergence sublayer (CS). The SAR segments protocol data units (PDUs) into ATM cells and reassembles ATM cells into (PDUs). [Pes93:p. 14] The convergence sublayer provides the necessary functions to support specific applications and is thus service dependent. [Stal92:p. 541] Figure 7 displays the format of the SAR PDUs for the different AAL types. [Stal92:p. 544]

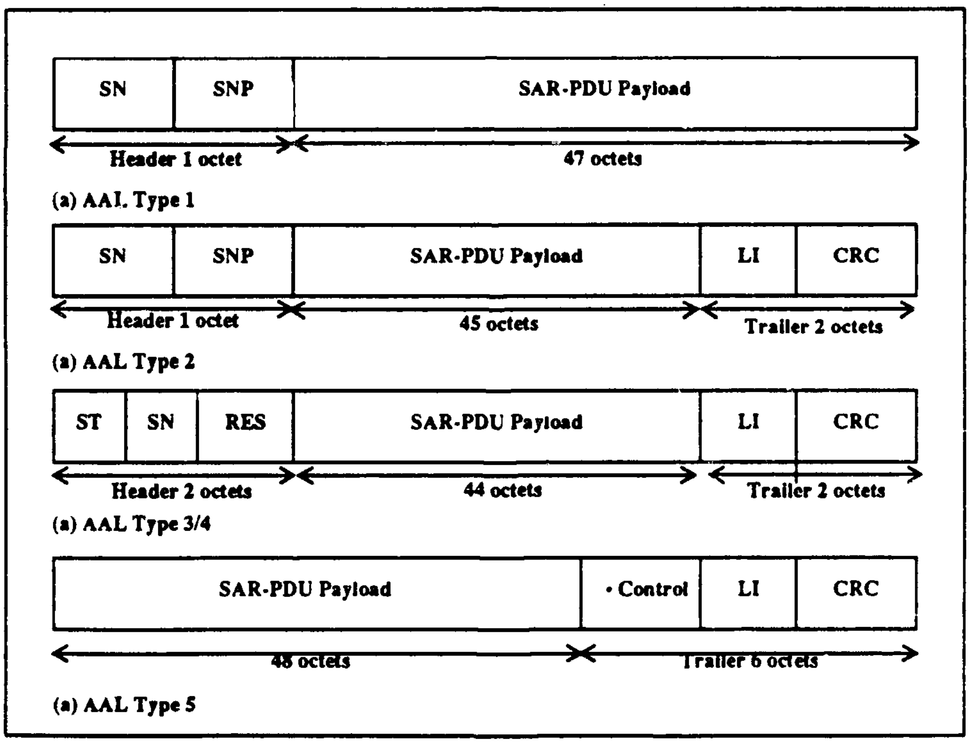

Figure 7: SAR-PDU Formats

a. AAL 1

AAL1 operations support constant bit rate services such as 64kbps voice. It also supports the transparent carriage of T1 over an ATM network called circuit emulation. AAL 1 provides the following services to the user·

- Transfer of Service Data Units at the same delivery rate as the source rate.
- Transfer of timing information between source and destinations.
- Transfer of data structure information.
- Indication of lost or errored information which is not recovered by the AAL itself.

[Depry93:p. 130]

b. AAL 2

AAL 2 provides the transfer of information with variable bit rates for Class B services such as variable bit rate video and audio. Additionally timing information is transferred between source and destination [Pes93:p. 13]. The following services are provided to the user:

- Transfer of variable source bit-rate SDU's.
- Transfer of timing information.
- Indication when information is errored or lost.

[Maz93:p. 41/15]

c. AAL 3/4

CCITT initially defined two distinct types, 3 and 4, for connection-oriented and connectionless data. However, it was then changed to a single 3/4 whose procedures could be applied to both connection-oriented and connections less data [Pes93:p. 13]. AAL 3/4 provides the transfer of Class C and D services. Examples of these services are connection oriented data transfer in the user plane, signaling in the control plane and the connectionless transfer of data associated with LAN interconnection [Pes93:p. 13]. Two modes of AAL 3/4 are defined:

- Message mode: AAL-SDUs are passed across the AAL interface in exactly one AAL Interface Data Unit (IDU). This provides more service for transport of fixed or variable length AAL-SDUs.
- Streaming mode: AAL-SDUs are passed in one or more AAL-IDUs. This mode provides the transport of long variable length AAL-SDUs. [Depry93:p. 133]

The AAL3/4 type provides the following services to the user:

- Assured operations: Flow control and retransmission of corrupted/missing CS-PDUs ensures delivery of AAL-SDUs
- Non-assured operations: Integral AAL-SDUs may be lost or corrupted and will not be corrected.

[Maz93:p. 41/16]

d. AAL 5

The ATM Forum has specified AAL 5 to better meet high speed connection-oriented data service needs. AAL 5 has smaller overhead and simpler processing requirements compared to AAL 3/4 (see Figure 7). It provides more bytes for the user payload [Depry93:p. 138] and allows the transport of noninterleaved data frames (i.e. IP packets) in a connection-oriented manner suitable for Class C services. [Pes93:p. 13]

E. ATM CONNECTIONS

ATM is connection oriented in the sense that end to end points are connected via a virtual connection. The header of a ATM cell contains information that associates each cell with a virtual connection. Two parameters identify this virtual connection: the Virtual Channel Identifier and the Virtual Path Identifier [Arm92:p. 1]. There is a hierarchial relationship between VPI's and VCI's. Virtual channels exist within virtual paths and have local significance within the VP only. Figure 8 illustrates this relationship [Stal92:p. 532]

1. Virtual Channels

Virtual channels are communication channels that route ATM cells. These channels are the basic switched entity in the ATM and together with Virtual Paths are essential to the ATM operation. Basic routing is accomplished by VCI translation in an ATM switch. A Virtual Channel (VC) is a routing entity for switched services and semi-permanent services. [Min9:,p. 555]

The use of multiple VCI values for multicomponent services provides an advantageous use of VCs. For example, video telephony can consist of three components: voice, video and data, each of which can be transported over a separate VC. This will allow

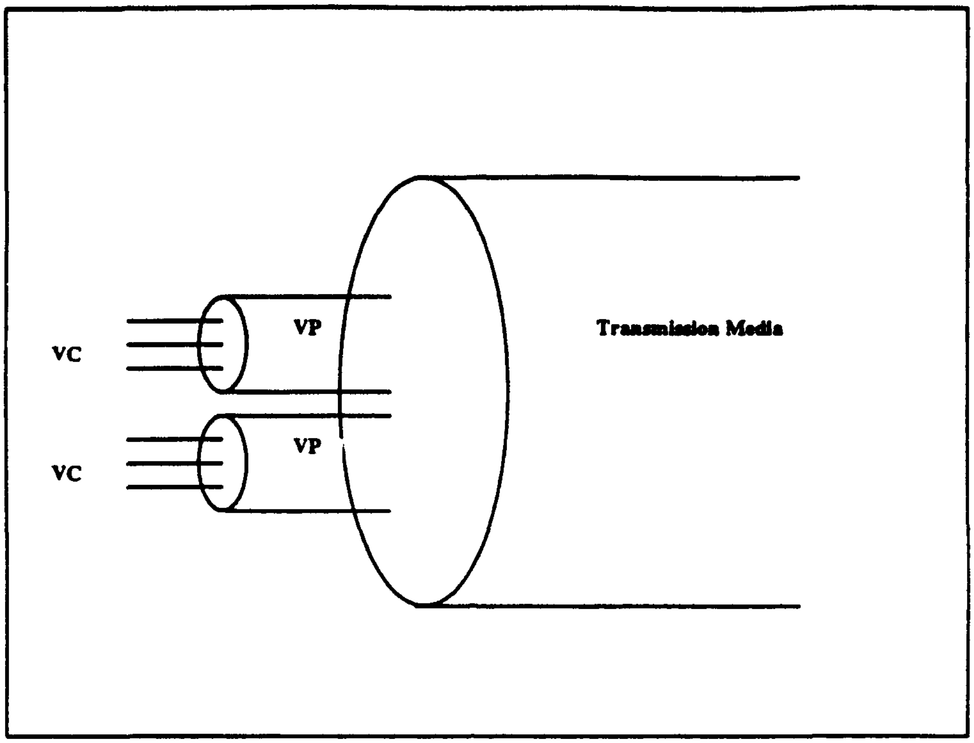

Figure 8: Virtual Channel and Virtual Path Relationship

the network to add or delete a component without interrupting the other components. [Depry93:p. 85] The virtual channel concept is well suited to multimedia.

2. Virtual Paths

Virtual Paths (VPs) are basically a bundle of VCs with the same VC endpoints [Min93:p. 555]. Virtual paths can be established for switched or semi-permanent basis [Min93:p. 556].

F. ATM SWITCHING

Switching in networks refers to the transportation of information from an incoming logical channel to an outgoing logical channel (point to multipoint requires more than one outgoing channel). Information in bit streams, packets, frames or cells arrive at input ports to the switch and are transported/switched to outgoing ports based on preestablished method of addressing [Depry93:p. 148]. In an ATM network the switching architecture must account for the characteristics of ATM technology. Specifically it must be able to

operate at a high speed and handle the statistical behavior to the ATM cells. An ATM switch must provide for routing, queueing, and header translation. [Depry93:p. 147]

There are many solutions to the architecture for ATM switches; a number of companies have ATM switches in the market and commercially deployed. In general the basic architecture looks like Figure 9 [New92:p. 91].

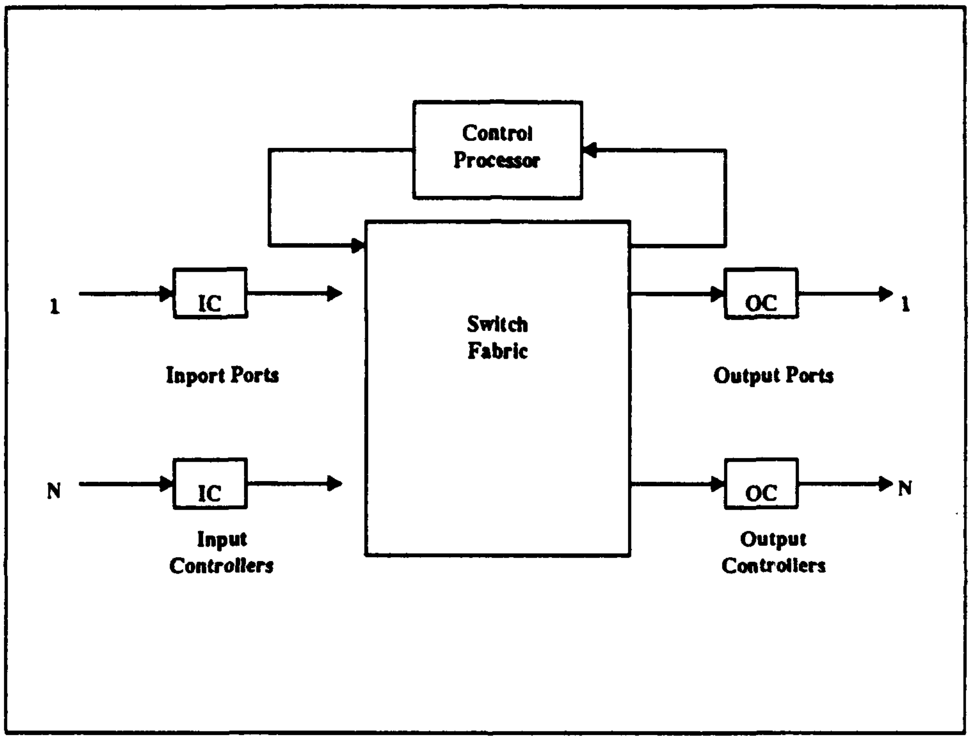

Figure 9: General ATM Switch Architecture

The input controllers perform header translation, the switch fabric performs routing, and queuing is performed by buffers strategically placed to make the switch as efficient as possible. Some ATM switch designs support multicasting by making multiple copies of incoming cells within the switch fabric and routing each of the copies to its required output port [New93:p. 91].

G. CONCLUSION

This chapter presented a general discussion of Asynchronous Transfer Mode (ATM) fundamentals. A transfer mode overview was given to demonstrate ATM's evolutionary development. Standardization was discussed to display the active work being accomplished

in this field and how DoD can help shape the standards to meet specific need. The B-ISDN Protocol Reference Model was discussed in relation to the OSI Protocol Reference Model to provide a conceptual understanding of how and where ATM fits into the big networking protocol picture. Finally some specific fundamentals were discussed including cell structure, ATM connections, and ATM switching in order to understand how ATM meets or will meet the performance parameters to be discussed in Chapter III. Several conclusions can be drawn from this chapter:

1. That ATM achieves low delay and high data rates with:

    - Reduced header functionality
    - Reduced information field.
    - No error protection or flow control on a link to link basis.
    - Optical fiber physical medium and SONET/SDH transmission structure.

2. That ATM is connection oriented and supports all information types.

3. That ATM is in a childhood stage of development with many important issues to be resolved.

4. That ATM is receiving much standardization activity.

III. ATM PERFORMANCE CHARACTERISTCS

The purpose of this chapter is to introduce baseline performance parameters for general communication networks and characterize ATM's capability using these performance parameters. This chapter will also serves to present the services of B-ISDN.

A. SEMANTIC TRANSPARENCY

1. Definition

Semantic transparency accounts for the accuracy of the information from source to destination, i.e., the correct transmission of bits with a limited number of errors [Depry93:p 21]. The probability of error is one of the most useful parameters used to describe digital communications systems and is labeled Bit Error Rate (BER) [Maz93:p. 28/7].

2. Bit Error Rate

The bit error rate or ratio (CCITT,1988a) is defined as the ratio of bits received in error to the total number of bits transmitted in a specified interval. [Maz93:p. 41/19]

$$\text{BER} = \frac{\text{Number of erroneous bits}}{\text{Total number of bits sent}}$$

The bit error rate is one of the most useful performance parameters to evaluate digital communication systems because it describes the quality of the system in simple terms. Either a bit arrives as transmitted or it does not. Also, the BER of several digital services have been quantified and thus a communication system can be determined to either meet or not meet these requirements [Maz93:p. 28/7]. The BER of a communication system is dependent on the physical transmission medium used and its susceptibility to the introduction of errors. Lost and incorrect bits due to transmission media are independent of

the use of ATM. [Depry93:p. 69] The quality of fiber transmission will allow ATM networks to guarantee a BER on the order of 10^{-8} [Pes93:p. 17].

3. Cell Error Rate

In packet oriented networks bits are grouped into packets or cells and errors occur because packets of information are lossed or misrouted. The cell error rate is the number of erroneous cells over the total number of lost cells transmitted. [Depry93:p. 37]

$$CER = \frac{\text{Number of erroneous packets}}{\text{Total number of packets sent}}$$

In a communication network, errors are caused by the transmission media and the switching/multiplexing systems. The cell error rate of an ATM network is determined by three factors:

- Transmission errors: Transmission errors occur primarily as a result of white noise in the transmission media and is therefore dependent on the quality of the chosen media. These errors occur independent of the protocols used in the communication network.
- Queue overflows: Queue overflows occur when a cell arrives at a node and there is insufficient space in the queue. The cell is therefore discarded.
- Misrouting: When bit errors occur in the header of a cell, the possibility exists that the cell will be routed to the wrong node in the network. These errors result in inadvertent cell insertsions in incorrect virtual channels.

[Depry93:p. 69]

a. Cell Loss Ratio

Cell loss ratio refers to the number of cells lost due to misrouting or congestion and equals the number of lost cells in a VC divided by the total number of cells sent into a VC [Depry93:p. 38]. Cell loss may occur due to header errors or due to queue overflows. Cell loss ratio is an important performance parameter in an ATM network [Maz93:p. 41/19]. For certain real time services, such as video, a cell loss may have a detrimental effect on the Quality of Service (QoS) guaranteed by the network. The quality

of fiber transmission and the advances in the switching architecture will allow ATM to provide a CLR on the order of 10^{-8} [Pes93:p. 17].

b. Cell Insertion Ratio

Cell insertion ratio refers to the number of cells incorrectly routed to a destination and equals the number of inserted cells over the total number of cells sent into a VC [Depry93:p. 38]. Cell insertions may occur due to header bit errors in the address field [Maz93:p. 41/20]. It is estimated ATM networks will guarantee CIR's on the order of 10^{-8} [Pes93:p. 17].

B. TIME TRANSPARENCY

1. Definition

Time transparency refers to the ability of a network to transport the information from source to destination with minimal delay [Depry93:p. 23]. Two parameters associated with time transparency are end-to-end delay and cell delay variation (delay jitter) [Depry93:p. 45]. Cell delay variation is the difference between the delay of cells in the same VC. It is caused mainly by variations in the queuing and adaptation buffers in the network nodes. [Maz93:p. 41/20] End-to-end delay is a more familiar performance parameter and is further discussed below.

2. End-to-End Delay

Delay is the time difference between the sending of the information and the receiving of the information [Depry93:p. 45]. There are various types of delay that contribute to the total end-to-end delay.

- Transmission delay (TD) is the delay caused by the physical medium and the distance between the source and destination.
- Processing delay (PD) is the delay caused by the nodes on the path between the source and the destination. It includes fixed switching delay (FD) and queuing delay (QD).
- Cell assembly delay is the time it takes to assemble a cell and cell disassembly is the time it takes to disassemble a cell. They are respectively called Packetization Delay (PD) and Depacketization Delay (DD).

[Depry93:p. 63]

End to end delay is caused by the transmission links and by the transit delays of the switches. ATM network delay characteristics are illustrated in Table 4.[2][Depry93:p. 67]

TABLE 4: ATM NETWORK DELAY CHARACTERISTICS

Cell Size[a]	32	64	32	64
TD	4000	4000	4000	4000
FD	128	256	32	64
QD/DD	400	800	100	200
PD	4000	8000	4000	8000
SD	900	900	900	900
D1	8528	12256	8132	12364
D2	13828	21956	13132	21364

a. Delay (in microseconds) for 150Mbps and 600Mbps interface. Link load: 80%; Cell Loss Ratio: 10^{-10}

Table 4 represents characteristic delays of an all ATM network (D1) and a combined ATM and non-ATM network (D2). The results indicate that for an all ATM network the delay for a 48 byte information field is approximately 10.4 milliseconds for a 150 Mbps user interface and 10.3 milliseconds for a 600 Mbps user interface. For an integrated non-ATM and ATM network the delay for a 48 byte information field is approximately 17.9 milliseconds for a 150 Mbps user interface and 17.3 milliseconds for a 600 Mbps user interface.

C. BANDWIDTH

ATM is based on a physical layer of optical fiber. Optical fiber transmission technology achieves a remarkable increase in transmission bandwidth. Engineers at Nippon Telegraph and Telephone Corporation (NTT) recently demonstrated transmission at the

2. The assumptions are 1000 km between source and destination; 2 synchronous switches, each with a delay of 450us (the average value allowed by CCITT).

rate of 20 Gbps over a distance of 632 miles [Irv93:p. 41]. Fiber is becoming the transmission medium of the future and the strategic plans of the IXC's and LEC's. Data from the FCC show the use of fiber has grown form 456,000 fiber miles at the end of 1985 to 2,385,000 at the end of 1991 [Irv93:p. 41]. The result of this influx of fiber into the public and private communication networks is a plenitude of bandwidth. The increase in bandwidth is such that the transmission media is no longer considered a bottleneck for communication networks. [Klien92:p. 36]

The standard transfer capacity of ATM cells for the User-Network Interface is 155.52 Mbps with a payload capacity of 149.76 Mbps. Since the ATM cell itself has 5 octets of overhead, the 48 octet information field equates to 135.631 Mbps of actual user infomation.The target 155.52 Mbps interface is symmetric and supports both optical and electrical interfaces. [Min93:p. 562]

A second User-Network Interface is defined at 622.08 Mbps with a payload capacity of 599.04 Mbps. The 622.08 Mbps interface supports both a symmetric interface and an asymmetric interface. [Min93:p. 564]

There are two types of transmission options for ATM cells. A cell-based physical layer requires no further framing of the ATM cells and is a continous stream of 53 octet cells. The advantage of this method is its simplified interface. [Stal92:p. 555]

The second type is a SDH-based physical layer. Framing is imposed using the STM-1 (STS 3) frame on the ATM cells. [Stal92:p. 555] The advantage of the SDH approach is that it can carry either ATM-based or STM-based payloads making it possible to transition to B-ISDN from the current public WANs. [Stal92:p. 557]

D. ATM SERVICES

Asynchronous Transfer Mode (ATM) is the standard switching, multiplexing, and transmission technology for Broadband Integrated Services Data Network (B-ISDN). It is essential to understand that ATM is the technology and B-ISDN is the service. CCITT has

categorized a range of B-ISDN services in recommendation I.211 into Interactive Services and Distribution Service. [Stal92:p. 497]

1. Interactive Services

Interactive services provide a two way exchange of information between end users or between end users and network operation. Interactive services are subdivided into conversational services, messaging services and retrieval services.

a. Conversational Services

Conversational services include video, sound, data and document type information for services such as broadband videotelephoney, high speed digital information transfer and high resolution image-communication transfer. Conversational service are real time.

b. Messaging Services

Messaging services include video and document type information for such services as video mail and document mail. The distinguishing feature of messaging service is that they offer storage-and-forward and message handling functions. Messaging services are not real time.

c. Retrieval Services

Retrieval services include (1) text, data and graphic information for services such as broadband videotex and (2) sound, still images, and moving pictures for video retrieval and high resolution image retrieval. The user has the capability to retrieve information stored in information centers.

2. Distribution Services

Distribution services are primarily one-way services that require the capability of broadcast and multicast in the communication architecture. Distribution services are sub-classified as services with user presentation control and service without presentation control. Information types include video, text, graphic and data for services such as TV

distribution, document distribution and data distribution. These services are also referred to as broadcast services and multicast services.

E. CONCLUSION

This chapter presented a discussion of the performance characteristics of a generic Asynchronous Transfer Mode (ATM) network and described the standardized services of B-ISDN. The estimated values for ATM's performance characteristics are based on research accomplished in recent years. As ATM matures as a technology, more accurate parameter values will be available. These parameter values are summarized in Table 5.

TABLE 5: ATM PERFORMANCE CHARACTERISTICS

BER	CLR	CIR	End-to-End Delay	Bandwidth
10^{-8}	10^{-8}	10^{-8}	A few hundred micro-seconds	155.52Mbps and 622.08Mbps

It is important that middle and high level mangers understand the performance characteristics of communication architectures so that a proper and thorough evaluation of various technologies can be made. When investing in the communication architectures, it is first necessary to define the requirements of the applications that will use the network with respect to the network performance attributes. The following chapter discusses the requirements of the Distributed Integrated Simulation application.

IV. THE REQUIREMENTS OF DIS

The purpose of this chapter is to define the requirements of the Distributed Interactive Simulation (DIS) communication architecture. The DIS communication architecture requirements are now being documented in the draft report *Communication Architecture of Distributive Interactive Simulation (CADIS)*, issued by the Institute for Simulation and Training (IST) [ISTA93]. This chapter examines these requirements and provides detailed discussion on bandwidth and multicasting requirements.

The communication architecture for DIS encompasses the workstations on a LAN at a simulation site connected to remote simulation sites by a wide area network. These local area networked simulation sites are connected to the WAN via a gateway or router. Simulations of various sizes have been proven to work at the local area and most of the research and experiments in simulation have been conducted at the local area. To expand the scope of simulations for a large number of entities at a large number of sites the communication architecture requirements need to be addressed.

The requirements for the DIS communication architecture have not been fully identified and documented. *Communication Architecture of Distributive Interactive Simulation (CADIS)* [ISTA93] and *The DIS Vision* [ISTB93] represent initial reviews of the requirements for the DIS communication architecture and are useful as starting points. It is generally agreed that the communication architecture for DIS must support the following requirements: multicasting, bandwidth, latency, and error handling [ISTB93:p. 26].

A. MULTICASTING

Multicasting is the concurrent transmission of information from a given user source to a group of target users[Zhong93:p. 157]. Multicast potentially allows a source to transmit

a packet of information only once. It allows the receivers to receive only pertinent information.

The need for multicast capability in DIS are two fold:

- To reduce the computational load on individual simulations hosts.
- To minimize traffic on limited network resources.

[Doris92:p. 281]

Multicasting services allow arbitrarily-sized groups to communicate via a single transmission by the source. This capability may provide the ability to create player groups in virtual worlds [Maced93:p. 3]. These player groups can be grouped by geographic location, by entity class, or by PDU types [Doris92:p. 295]. The primary criterion for multicast groups is by exercise such that DIS could support multi-exercise simulations [Doris92:p. 282]. The essential elements of multicasting for DIS are:

- Each host may belong to more than one multicast group at the same time.
- Each host must be able to drop its membership from a group and/or join another at will.
- Members of a multicast group may reside anywhere on the network.
- The maximum number of members in a single multicast group shall be large enough to encompass all hosts in a DIS exercise.
- The transmitting host need know nothing about a group except the address of the multicast group to which it is sending PDUs.
- Change in membership of a multicast group shall be entirely initiated by the receiving host.
- The number of simultaneous multicast groups shall be entirely initiated by the receiving host.

[Doris92:p. 281]

1. Need For Multicasting: Bandwidth Reduction

The reduction of bandwidth due to multicasting services is demonstrated by Doris in [Doris92]. For each type of multicast grouping, i.e., location, entity, and PDU, sample calculations are provided to demonstrate the bandwidth savings. Doris concluded location groupings to be the most promising and the bandwidth savings due to this type of multicasting are repeated here as an illustration of the benefits of multicasting. The bandwidth requirements in Table 6 are measured in PDUs per second for a 1000 entity simulation. [3][Doris92:p. 290]

TABLE 6: PDU/SEC FOR A 1000 ENTITY SIMULATION

AOI Grid Size (km)	25	50	100	250	500
Total Number of MCA Groups	1600	400	100	16	4
Groups per Host (max)	81	25	9	4	4
PDUs per Group	3	12	50	312	1250
PDUs/sec rec'd per host	243	300	450	1248	5000

The results indicate that the number of PDUs/sec received per host decreases with an increase in the number of Multicast Address (MCA) groups. If an average PDU size is 300 bytes, 2400 bits, an increase in MCA groups from 4 to 400 translates into a data rate reduction from approximately 12 Mbps to 960 Kbps. [Doris92:p. 290]

2. Problem With Multicasting.

The problem with multicasting is that it is not widely available in the WAN [ISTB93:p. 4]. Many research efforts are however addressing the issue. SIMNET uses a reservation/multicast protocol called ST that was designed for multicast of real time speech applications. The current SIMNET system architecture is based on LAN broadcast capability. Each node on every LAN broadcasts its local state information to the entire world. This method requires sufficient processing power at each node to filter through all the remote traffic and sufficient bandwidth by the WAN gateways, switches and transmission media. This method is inefficient in its use of resources as most nodes in a simulation need only interact with a subset of other nodes. [Chung92:p. 176]

NPSNET IV uses the IP multicasting protocol. IP multicast is the Internet standard for multicast and is receiving energetic research as a possible solution to the multicast requirement for the communication architecture. IP multicast offers efficient, low

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3. Assumptions made regarding the manner in which the gaming area is divided into AOI's are: (1) the gaming area is reasonably large: 100,000 square kilometers. (2) the radius of each entity is 100 km. (3) the AOI grid size is variable based on the number of multicast groups the entity would belong to which is calculated by: Groups per host = $((2*\text{Radius of Interest}/\text{AOI size})+1)^2$
The results shown are based on 1000 entities with a worst case of 5000 PDUs per second.

delay delivery to unknown or frequently-changing destinations. NPSNET-IV is the first DIS application to use the IP multicast protocol. [Maced93:p. 6]

The problem with IP multicast is that it is not an ISO standard. Also the trade- offs exist between reliability and speed. Most other distributed simulations have employed some form of broadcast or point to point communications. Broadcast requires that all nodes examine a packet even if the information is not intended for that host; and point-to-point communication requires the establishment of a connection or path form each node to every other node. IP multicast uses the User Datagram Protocol (UDP) and therefore is an unreliable connectionless service. [Maced93:p. 7]

B. BANDWIDTH

The available network bandwidth determines the size and richness of a virtual environment. On a local area network this is not the major issue because technologies are relatively inexpensive and the number of users is often limited. On a wide area network bandwidth is generally limited to T1 and T3 rates (1.5Mbps and 45 Mbps) and the number of users is larger. [Maced94:p. 4] The wide area network has not represented a bottleneck for simulations in the past [Chung92]. The limited number of entities of past simulations has not required more than a 15 Mbps requirement. However, to meet the 1995 and year 2000 DIS goals of 10,000 and 100,000 entities, respectively, bandwidth becomes a primary performance consideration of the wide area network.

An approach for bandwidth estimates for interactive simulations is given in the CADIS guidance document. This four step method provides estimates for the data rate requirements of the DIS communication architecture:

- Step 1: Define the types of PDUs that generate the most traffic.
- Step 2: Estimate the PDU size.
- Step 3: Estimate the frequency at which entities generate PDUs.
- Step 4: Determine the number of each major entity that will participate in the exercise. [Doris93:p. 287]

Using this formula the estimated bandwidth requirements for a 1,000 entity simulation is approximately 5.6Mbps minimum and 15Mbps maximum.[4] This technique can be

extended to estimate the requirements of the 10,000 and 100,000 entity goals. Data rate requirements for a 10,000 entity simulation is approximately a ten fold increase in the data rate, thus requiring 150Mbps maximum and 56Mbps minimum. Data rate requirements for a 100,000 entity simulation is approximately a hundred fold increase in the data rate, thus requiring 1.5Gbps maximum and 56Mbps minimum.

The *ATD-1 Architecture White Paper* estimates bandwidth requirements for a 100,000 entity simulation with 100 locations. Using the Loral assumptions, the data rate requirement are 150 Mbps on average and 250 Mbps maximum.[5] Using BBN assumptions of generating 1.5Kbps per object on average and 30 Kbps at maximum, the data rate for 100,000 entities will be 150 Mbps on average and 3000 Mbps maximum.[6]

The results of these bandwidth estimates for 10,000 and 100,000 entity simulations is that the WAN will have to deliver between 56Mbps minimum and 150Mbps maximum to each site by the year 1995 and 150Mbps minimum and 3.0Gbps maximum by the year 2000.

C. LATENCY

The requirement for latency is perhaps the least analyzed requirement for the communication architecture. Without proper analysis of the types of data on the network and their specific delay requirements, the best that has been done is to recognize that the human being cannot determine changes in the environment greater then 100ms [ISTB93:p. 26]. This is the minimum limit on delay. Other estimates for delay have been stated as 300 ms for 'loosely' coupled entities. Thus an end-to-end delay in the range from 100ms to 300ms has been initially determined as a requirement of the communication architecture.

4. It assumes that the majority of the traffic in the communication network will result form 5 types of PDUs: Entity State, Fire Detonation, Emission, and Signal.

5. The Loral assumptions are: 1 APDU per second for each entity on average with peak being 2.5 APDU/s and average length of 1.5kb/APDU. Air simulations generate between 1 APDU/s per vehicle and 3 APDU/s/vehichle.

6. BBN assumptions are: Average APDU size is 200 bytes, there will be between 2 and 15 APDU/s with an average being about 1 APDU/s per entity.

D. ERROR DETECTION

Error detection refers to the ability of the communication architecture to detect and possibly correct errors in the transmitted data. This function is accomplished at various layers in the OSI protocol reference model. In the DIS environment different PDUs have different requirements for the accuracy in which they are transmitted. Currently there are 3 different levels of accuracy:

- Best Effort Multicast
- Reliable Effort Unicast
- Best Effort Unicast

[ISTA93:p. 10]

Best effort multicast and reliable effort unicast require upper layer support for additional processing of corrupted packets for determination of correcting or discarding the packet. [ISTA93:p. 11]

E. CONCLUSION

This chapter has presented the background of the Advanced Distributive Simulation (ADS) movement and introduced the related standard movements: Distributive Interactive Simulation (DIS) and its related standard the Communication Architecture for Distributive Interactive Simulation. The communication architecture requirements were discussed and expanded on in terms of estimated calculations for data rates and the need for multicasting.

V. ANALYSIS

A. INTRODUCTION

The purpose of this chapter is to analyze how B-ISDN may help support the communication architecture requirements of DIS. The method used for analysis is the approach suggested by SRI International in [SRI90]. First, the DIS requirements presented in Chapter IV are mapped into a format compatible with the CCITT class of service standards used to develop and categorize common carrier services. Second, the B-ISDN service aspects, CCITT recommendation I.211, as discussed in Chapter III, are mapped into a similar format. Third, an analysis of the attribute values of the DIS and B-ISDN is presented. Additional discussion is provided for the requirements of multicasting and the need for Quality of Service (QoS) parameters for DIS.

The method of analysis used in this chapter makes several assumptions about wide area networks (WANs). Wide area network in this context refers to the WAN subnetwork consisting of the first three layers of the OSI protocol reference model. The focus is on dealing with traffic as it is presented to the WAN subnetwork and not on the issues associated with the reduction of network load in the upper layers of the OSI model. [SRI90:p. 42] This issue of multicasting is an exception, since this capability will be a necessary feature of B-ISDN.

B. STANDARDIZED REQUIREMENTS OF DIS

The first step in analyzing a WAN architecture's suitability for any application is to determine the requirements of the application and map these requirements into a format compatible with the common carrier class of service standards. The advantage to this approach is that it provides a concise description of the application requirements and makes these requirements compatible with the standard format and approach used by CCITT. [SRI90:p. 43]

The requirements of the DIS communication architecture as discussed in Chapter IV are:

- Multicasting
- Bandwidth
- Latency
- Error control

Attempting to map these requirements into a format compatible with CCITT standards reveals the shortcomings of the requirements definition of the CADIS draft document [ISTA93]. Additional requirements of DIS need to be defined. The *ATD-1 Architecture White Paper*, [SRI90], can be used to complete the requirements definition of DIS. This white paper is an attempt to evaluate N-ISDN as a possible WAN candidate for distributive simulations. Table 7 lists the requirements of DIS in this format [SRI90:p. 48]. What cannot be mapped, i.e., latency and error will be discussed as Quality of Service (QoS) issues.

TABLE 7: DIS STANDARDIZED REQUIREMENTS

ATTRIBUTES	POSSIBLE ATTRIBUTE VALUES
Information transfer mode	Circuit Packet
Information transfer rate	56Kbps (min) 3.0Gbps (max)
Information transfer capability	Unrestricted Voice; Audio; Imagery; Video; digital information; Connection; Connectionless;
Structure	Service data unit integrity Unstructured
Establishment of communication	Demand Reserved
Communication configuration	Point-to-point Multipoint Broadcast
Symmetry	Unidirectional Bidirectional symmetric Bidirectional asymmetric
Error handling	None Detection Recovery Forward error control

1. Information Transfer Mode

DIS will require a transfer mode that combines the capabilities of circuit switching and packet switching. The circuit switching attributes required are reserved resource and guaranteed throughput for the handling of constant rate data streams and connection oriented services such as voice and CBR video. The packet switching characteristics are required for the transfer of variable bit rate, connectionless services such high speed data transfer. [SRI90:p. 44]

2. Information Transfer Rate

As discussed in Chapter IV the transfer rate of DIS will range from 56Kbps to 3.0Gbps. It is important to recognize that this bandwidth/data rate is required at each site and that these estimates represent a best case/worst case range at the WAN point of presence [SRI90:p. 45]. This constitutes a requirement for the WAN to accommodate a wide range of bandwidths and bandwidth on demand for instances of entity increases and decreases at individual simulation sites.

3. Information Transfer Capability

Transfer capability refers to the types of information the service will provide. For DIS the types of information are:

- Voice: For voice circuits in the simulation and for simulation coordination and control.
- Video: For videoconferencing, specified as a future requirement for coordination and control.
- Imagery: For map transfer.
- Audio: For simulation realism.
- Unrestricted digital information: For transfer of PDU traffic.
- Connectionless packet: For transfer of PDU traffic.
- Connection-oriented packet: For transfer of PDU traffic.

[SRI90:p. 46]

4. Information Transfer Structure

Transfer structure refers to the ability of the network to deliver data to the destination with a given structure. This attribute focuses on the delivery of bits and not bytes or PDUs. Data flows that require specific delay and loss characteristics, such as

appearance PDUs, are grouped under Quality of Service (QoS). Requirements for information structure are:

- Service data unit integrity.
- Unstructured.

[SRI90:p. 48]

5. Connection Establishment

The DIS WAN requirements for connection establishment will probably be reserved and demand [SRI90:p. 46]. Due to the nature of simulations, exercise sites must be able to request reserved connections for the duration of the exercise and demand other services as the simulation progresses.

6. Connection Configuration

Intersite connectivity will require point to point connections, point to multipoint connections (multicasting) and broadcast capability. Voice service and some PDU services will require point to point connections. Videoconferencing and some PDU services will require point to multipoint. Broadcast capability is required for the transmission of low data rate control information. [SRI90:p. 46]

7. Connection Symmetry

PDU traffic falls under the category of unidirectional. Voice commutations require bidirectional symmetric and other data flows such as exercise management functions require bidirectional assymmetric. [SRI90:p. 47]

8. Quality of Service (QoS) Requirements

Quality of Service (QoS) is a set of measures that describe a degree of performance a service requires. These performance requirements will be different for various services. A wide area network, which will handle all types of services on a homogeneous network, will have to meet these varying performance requirements. QoS in an ATM layer service is characterized by a number of parameters, these are:

- **Bit Error Rate (BER)**
- **Cell Loss Rate (CLR)**
- **Cell Insertion Rate (CIR)**
- **End to End Delay**
- **Cell Delay Variation**

[Maz93:p. 41/19]

When designing a communication architecture, existing and future application QoS parameter values need to be defined. Network performance parameter values must meet or exceed the set of QoS parameter values to allow and ensure the communication architecture meets end user needs. [Maz93:p. 41/18]

In this context, the requirements of the DIS communication architecture not addressed in preceding sections must be defined in terms of the Quality of Service (QoS) requirements. These parameters are necessary if a simulation exercise is to use public WAN bearer services. This is especially true for B-ISDN services where the QoS is negotiated and guaranteed before and for the duration of the service. The QoS requirements for the information types of DIS have not been previously addressed. The parameter values are estimated here by determining each information type's sensitivity to the QoS parameters.

It can generally be agreed that each information type has certain characteristics that require high, moderate or low values for these QoS parameters. It is also agreed that certain values for the QoS parameters may be labeled high, moderate or low. For example a BER of 10^{-11} is considered very low and a BER of 10^{-3} is considered very high. Thus, if an information type is sensitive to a parameter it requires a low value for that parameter. Table 8 represents the scales used to determine the QoS parameter values for DIS.

TABLE 8: QOS PARAMETER SCALE

Scale	BER	CLR	CIR	End to End Delay	Cell Delay Variation
Low	10^{-8}	10^{-5}	10^{-5}	100ms	10ms
Moderate	10^{-5}	10^{-4}	10^{-4}	250ms	15ms

TABLE 8: QOS PARAMETER SCALE

Scale	BER	CLR	CIR	End to End Delay	Cell Delay Variation
High	10^{-3}	10^{-3}	10^{-3}	500ms	20ms

- Voice: Voice is a real time information type and is highly sensiti·‹ to end-to-end delay and delay variation. It is moderately sensitive to cell loss and information loss. [Maz93:p. 41/18]
- Video: Video is a real time information type and is highly sensitive to end-to-end delay and delay variation. It is moderately sensitive to cell loss and relatively insensitive to information loss (BER). [Yam93:p. 13]
- Audio: Audio is relatively insensitive to end-to-end delay and delay variation. It is highly sensitive to information loss and cell loss and thus requires low parameter values for BER and CLR.
- Imagery: Imagery can tolerate moderate delay and moderate cell loss and information loss. Data rate is important in imagery transfer.
- High Speed Data: For DIS purposes high speed data is moderately sensitive to information loss (BER) and highly and moderately sensitive to delay. Tightly coupled entities are highly sensitive to end-to-end delay and delay variation [ISTA93:p. 5]. Loosely coupled entities are moderately sensitive to end-to-end delay and delay variation [ISTA93:p. 5]. DIS is moderately sensitive to PDU loss (cell loss). Due to the distributed nature of a simulation it is important to keep each simulation sites' database current and accurate.

These estimates are given in Table 9.

TABLE 9: DIS QOS PARAMETER VALUES

Data Rate	Information Type	BER	CLR	CIR	End to End Delay	Cell Delay Variation
64Kbps	Voice	10-5	10-4	10-3	100ms	10ms
64Kbps-2Mbps[a]	Video	10-5	10-5	10-3	100ms	10ms
1 Mbps[b]	Audio	10-8	10-5	10-3	500ms	20ms
2Mbps-130Mbps	Imagery	10-8	10-5	10-3	250ms	15ms

TABLE 9: DIS QOS PARAMETER VALUES

Data Rate	Information Type	BER	CLR	CIR	End to End Delay	Cell Delay Variation
56Mbps-3.0Gbps[c]	Unrestricted High Speed Data (Connection & Connection-less)	10-5	10-5	10-3	100ms-250ms	100ms-250ms

a. Assumes H.261 standards.
b. Assumes stereo quality.
c. 1995 low data rate estimate to the year 2000 high data rate estimate.

C. EVALUATION OF B-ISDN

The B-ISDN information transfer attributes are listed in Table 10 in a format compatible with CCITT standards. These attribute values are taken from discussion and references in Chapter III and CCITT recommendation I.211 B-ISDN Service Aspects.

TABLE 10: B-ISDN ATTRIBUTE VALUES

ATTRIBUTES	POSSIBLE ATTRIBUTE VALUES
Information Transfer Mode	Asynchronous Transfer Mode
Information transfer rate	155.52 Mbps 622.08Mbps For further study
Information transfer capability	Unrestricted Voice; Audio; Imagery; Video; digital information; Connection; Connectionless;
Structure	For further study
Establishment of communication	Demand Semi-Permanent
Communication configuration	Point-to-point Multipoint Broadcast
Symmetry	Unidirectional Bidirectional symmetric Bidirectional asymmetric

1. Information Transfer Mode

As discussed in Chapter II, B-ISDN is based on the Asynchronous Transfer Mode (ATM) standard. This transfer mode offers characteristics of both circuit switching and packet switching. ATM was developed to take advantage of several transfer modes in one type of network communication technology.

- AAL 1 provides connection oriented circuit switch like transfer for voice.
- AAL 3/4 provides connection oriented and connectionless packet switch like transfer for high speed digital information[7]

[Cavan93:p. 5]

2. Information Transfer Rate

The transfer rate requirements of DIS have been estimated to be in the range of a 56Kbp to 3.0 Gbps. The current standard rates for B-ISDN are described in Chapter III. ATM services are expected to run over SONET carriers at SONET speeds. The current speeds are standardized at OC-3 (155.52Mbps) and OC-12 (622.08Mbps) with a future expansion potential to OC-48 (2.4 Mbps). Currently B-ISDN standards meet the maximum data rate requirement for the 1995 year goal of 150Mbps maximum for 10,000 entities. The year 2000 goal maximum of 800Mbps - 3.0 Gbps is currently not met, but the scalability of ATM and future plan for B-ISDN will make it possible to meet this target.

3. Information Transfer Capabilities

The information transfer capabilities of B-ISDN were listed in Chapter III. These standardized class of services will meet the requirements of the DIS transfer capabilities as shown in Table 11.

TABLE 11: B-ISDN CLASS OF SERVICE EXAMPLES

Class of Service	Type of Information
Class A	Voice

7. Connectionless data service over an ATM network has been defined in draft Recommendation I.364. A number of connectionless service functions (CLSF's) exist throughout the network. these CLSF's act as cell base routers for connectionless data unit transmission across the network.

TABLE 11: B-ISDN CLASS OF SERVICE EXAMPLES

Class of Service	Type of Information
Class B	VBR Video
Class C	Connection-oriented data transfer
Class D	Connectionless data transfer

4. Establishment of Communications

B-ISDN will offer both switched services and semi-permanent services. Switched services can be thought of as demand services. A customer requiring n x 64Kbps switched service will be able to establish these connections on demand. Thus a simulation exercise requiring another voice circuit at a particular site may demand more bandwidth from the common carrier. B-ISDN will also offer semi-permanent services. These are reserved services set up prior to an exercise based on the requirements and extent of the exercise.

5. Communications Configuration

B-ISDN will provide point to point capabilities and future requirements for B-ISDN will provide point to multipoint (multicasting) as well as broadcast capability. This assumption is well founded as the push for distribution TV and distribution document services will drive the technology.

6. Symmetry

The standardized B-ISDN services discussed in Chapter III will require three types of communications symmetry. These are:

- Unidirectional: For applications such as traffic monitoring.
- Bidirectional Symmetric: For applications such as Tele-shopping and Tele Advertising.
- Bidirectional Asymmetric: For applications such as Building Security.

[Stal92:p. 499]

7. Multicasting

An essential feature of B-ISDN is multicasting. Multicasting is required to support the distribution services discussed in Chapter III, such as video distribution and

data distribution. The capability for multicasting in B-ISDN is being researched as a capability of the ATM switches. Zhong proposes a copy network structure that guarantees the cell sequence under all types of traffic situations. These ATM switches are usually cascaded combinations of a copy network and a point-to-point switch. [Zhong93]

Wei in [Wei93] proposes a solution to multicasting problem by applying IP multicast over ATM. The problem with applying IP multicast over an ATM network stems from the ATM network being connection oriented. Since the connection is set up in advance of data transfer, the ATM cells carry a small routing field, i.e., VCI and VPI pair. If cells from different sources are multiplexed onto the same VC, they carry the same VPI/VCI routing field. There is not a straightforward way to distinguish cells from different sources. The resequencer solves this problem by designating a source in a multicast group as a resequencer. The purpose of the resequencer is to receive multicast cells from all other sources in the group and buffer them until all cells of a PDU are received. The resequencer forwards all cells of a PDU onto a single outgoing VC. The VC of the resequencer is a point to multipoint connection. Connections among the resequencers are bidirectional. A user-resequencer connection is point to point. Figure 10 shows this solution to multicasting. [Wei93:p. 6]

There are many proposed solutions to the multicasting problem for ATM networks. Broadband services will require multicasting and the public WAN's will eventually provide the capability to multicast. Public carriers are committed to ATM standards and services of Broadband Integrated Services Digital Network (B-ISDN). [Blum92:p. 25]

8. Quality of Service

The Quality of Service (QoS) requirements for DIS which were previously estimated allow the analysis of B-ISDN bearer services in terms of specific characteristics for each information type. Currently there is not a standardized set of QoS parameters an

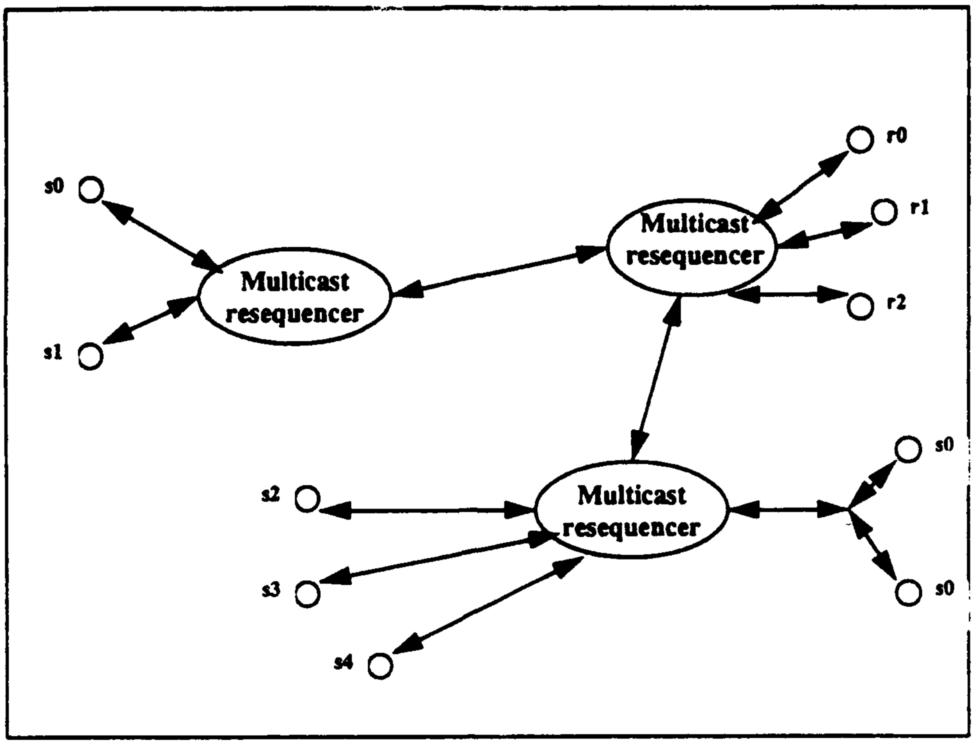

Figure 10: Resequencer and Group Multicast Tree Model

ATM network must meet. However, several estimates have been made and are useful in determining B-ISDN's capability to support DIS information requirements.

Values for particular bearer services based on a literature survey and analysis made at the National Technical University as part of the Research for Advanced Communication in Europe (RACE) project are given in Table 12 along with sample applications which may use these services. [Maz93:p. 19]

TABLE 12: POSSIBLE B-ISDN BEARER SERVICES

Bearer Service	Application
64 Kbps	Telephony; data; videotelephoney
2x64 Kbps unrestricted	Videotelephoney
384Kbps unrestricted	Videotelephoney/conferencing; data
1.92 Mbps	Videoconferencing: data

TABLE 12: POSSIBLE B-ISDN BEARER SERVICES

Bearer Service	Application
2.048 Mbps	Circuit emulation
> 2 Mbps up to < 130 Mbps	Data; image; video
Approx. 1Mbps unidirectional	Stereo sound contribution
45 - 130 Mbps	TV contribution
8.488 Mbps	Circuit emulation

Provisional QoS parameters for these bearer services were also estimated and are listed in Table 13. [Maz93:p. 19]

TABLE 13: POSSIBLE QOS PARAMETER VALUES

Bearer Service	BER	CLR	CIR	End to End Delay	Cell Delay Variation
64 Kbps	10^{-6}	10^{-4}	10^{-3}	400ms	20ms
2x64 Kbps	10^{-6}	10^{-4}	10^{-3}	200ms	20ms
384-1.92 Kbps	10^{-7}	10^{-5}	10^{-3}	200ms	20ms
> 2Mbps	10^{-7} w/FEC 10^{-8} w/o	10^{-5} w/FEC 10^{-9} w/o	10^{-3}	200ms	20ms
Approx 1Mbps	10^{-7} w/FEC 10^{-8} w/o	10^{-5} w/FEC 10^{-9} w/o	10^{-3}	500ms	20ms
8.488 Mbps	10^{-7} w/FEC 10^{-8} w/o	10^{-5} w/FEC 10^{-9} w/o	10^{-3}	80ms	10ms

Without specific CCITT standards for the types of bearer services and the QoS parameter values for these bearer services, these estimates will be used to evaluate the potential of B-ISDN to meet the DIS QoS parameter requirements.

Voice will require a data rate of 64 Kbps. Comparing Table 9 and Table 13 the estimated parameter values for voice are met for BER, CLR and CIR, however the end-to-end delay and delay jitter requirements are not met.

Video will require data rates between 64 Kbps to 2 Mbps. This translates into a bearer service of 64 Kbps - 1.92 Mbps. The QoS parameter values BER, CLR and CIR are met by the bearer services. End-to-end delay will require more stringent network performance.

Imagery will require a data rate in the range of 2Mbps to 130 Mbps. This translates into the greater than 2Mbps bearer service. The BER, CLR and CIR performance requirements are met with forward error coding (FEC). The end-to-end delay requirements are also met.

High speed data will require data rates from 56 Mbps to 3.0 Gbps. The bearer service will have to guarantee values similar to the greater than 2 Mbps bearer service values with more stringent parameter values on end-to-end delay and delay variation.

The results indicate that the outlook for B-ISDN bearer services to meet the QoS requirements of DIS is positive. As standards become complete and bearer services, with associated QoS parameters, are defined this approach can be expanded. Also, as DIS QoS parameter values are defined they can be better matched to the B-ISDN standards.

D. CONCLUSION

This chapter analyzed B-ISDN's potential to meet the DIS communication architecture requirements of Chapter III. The requirements of DIS were systematically defined by mapping them into a format compatible with CCITT standards used to evaluate and develop common carrier services. The B-ISDN standards were then discussed to determine if its services could help meet the DIS requirements. The general conclusion is that B-ISDN will meet or exceed the requirements of DIS. Further discussion on multicasting was provided to illustrate that the push for this capability in the WAN is strong for several reasons, the most important being industry's need to provide distribution

services. Finally the Quality of Service (QoS) parameters of DIS were estimated using a simple technique of sensitivity. These QoS parameters were then compared to the estimated QoS parameters of the B-ISDN to determine how B-ISDN might meet these values.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

1. Asynchronous Transfer Mode (ATM)

Chapter II presented a discussion of the Asynchronous Transfer Mode (ATM) technology. ATM is an emerging technology that provides high quality, high speed switching and multiplexing capabilities. It uses fixed length cells with reduced header functionality and no error protection or flow control on a link to link basis to achieve low delay characteristics and high data rates.

ATM is based on an optical fiber transmission medium and SONET/SDH transmission structure to achieve high data rates with scalability:

- 155Mbps (SONET OC3)
- 622Mbps (SONET OC-12)
- 2.4Gbps (SONET OC-48)

ATM is connection oriented and uses Virtual Circuits (VCs) and Virtual Paths (VPs) to route ATM cells. VCs and VPs allow for switched and semi-permanent connectivity. Multiple VCs allow for multimedia services over one homogenous network. Control of VCs by QoS parameter negotiation prior to connection allows ATM networks to guarantee bandwidth and other QoS parameter values.

ATM uses adaption functions (AALs) to accommodate data formats and operating characteristic of different services. ATM adaption functions help higher layer protocols adapt to the use of ATM as the lower layers (Data Link and Physical).

There are several issues concerning ATM technology that are currently being addressed. These are:

- Multicasting
- ATM interoperability with multiple protocols; particularly TCP/IP.
- ATM over satellite
- ATM for lower data rates.

The standardization of ATM is being accomplished by the interaction of traditional standard groups, industry and end users. ATM is not an interim solution but the future technology of broadband networks.

2. Broadband Integrated Services Digital Network (B-ISDN)

Chapter III presented the Broadband Integrated Services Digital Network and general performance characteristics of an ATM network. The services offered by B-ISDN are conversational, messaging, retrieval, and distribution. The services B-ISDN will offer are not as important to DoD as are the characteristics of these services. These characteristics include:

- High data rates
- Integrated multimedia (i.e. voice, video, audio)
- Bidirectional symmetric and asymmetric transmission modes
- Multicast and broadcast capability
- Reserved and demand connection configuration

3. DIS Communication Requirements

Chapter IV presented the communication architecture requirements of Distributed Interactive Simulation (DIS). Bandwidth requirements represent a qualifying parameter for the future architecture. Bandwidth estimates for 1000, 10,000, and 100,000 entity simulations reveal bandwidth requirements from 56Mbps to 3.0 Gbps to meet 1995 and the year 200 goals of DIS.

Multicasting capability will be required of the DIS communication architecture to provide the capability to create multi-exercise simulations on one communication architecture and to reduce bandwidth requirements.

The QoS requirements presented in Chapter V represent estimates of the level of quality the information types of DIS will require. These parameter values are given as an illustration of the degree of specificity in which DIS requirement must be defined.

B. CONCLUSIONS

B-ISDN can help meet the communication architecture requirements of DIS. B-ISDN is a promising common carrier service based on the emerging Asynchronous Transfer Mode (ATM) technology. B-ISDN promises unique capabilities in a public WAN. These include:

- Flexibility to handle a mix of service demand.
- Ability to handle a range of user traffic source rates using the same technique and equipments
- A general transport infrastructure to handle by adaptation a very wide range of traffic/ service types.
- Possibility of service integration on the same medium. An important consideration for broadband networks where service types and demand are still ill-defined.

[Maz9 3:p. 41/8]

QoS parameters and standard bearer services for B-ISDN have not been defined. Estimates for the bearer services and QoS parameters were presented to allow discussion on how B-ISDN could help meet the QoS parameters of DIS. This discussion represents an attempt to evaluate future WAN services to meet DIS requirements.

Performance parameters are difficult to state. Impairments for voice include gaps in speech, long echo-free delays, burst of errored bits, speech clipping and phonemic distortions. Impairments for video include edge business, blocking, dirty window, image persistence and jerky motion. [Wolf91:p. 24]

Another difficulty in quantifying QoS parameters for B-ISDN and DIS is the integration of voice, video and data. Integrated performance measurements may be required since total system performance may not be a simple function of the performance of each separate component but a combination of each. [Wolf91:p. 25]

The successful deployment of B-ISDN will depend on the end user needs for new applications that require an underlying high performance data network. These applications will have similar characteristics as DIS. They will be geographically distributed, require transmission of large amounts of data, and require low latency [Rans92:p. 30].

C. RECOMMENDATIONS

DoD can no longer afford unique solutions to its wide area network needs. It must align its application requirements to the services offered by the common carriers. The common carriers have invested billions of dollars into their communication architectures and are investing billions more into research for the future communication networks. DoD needs to influence the technology of these future networks by defining their communication architecture needs. To determine DoD communication architecture requirements, the existing and future services, along with their specific requirements, must be defined. These requirements must be defined at a level of specificity that allows a complete and thorough evaluation of common carrier services.

Definition of DIS requirements through data modeling and QoS parameter experiments is needed such that DoD can aggressively pursue and influence the standardization of B-ISDN and ATM. These requirements should be mapped into a format compatible with international standards to ease the evaluation of common carrier services.

APPENDIX A: GLOSSARY

AAL	ATM Adaption Layer
ADS	Advanced Distributive Simulation
ANSI	American National Standards Institute
ARPA	Advanced Research Projects Agency
ATM	Asynchronous Transfer Mode
BER	Bit Error Rate
B-ISDN	Broadband Integrated Services Digital Network
CADIS	Communication Architecture for Distributive Interactive Simulation
CBR	Constant Bit Rate
CCITT	Consultative Committee for Telephone and Telegraph
CER	Cell Error Rate/Ratio
CIR	Cell Insertion Rate/Ratio
CLR	Cell Loss Rate
DARPA	Defense Advanced Research Projects Agency
CS	Convergence Sublayer
DIS	Distributive Interactive Simulation
DoD	Department of Defence
IDU	Interface Data Unit
IP	Internet Protocol
ITU-T	International Telecommunications Union-Telecommunications
IXC	Interexchange Carrier
LAN	Local Area Network
LEC	Local Exchange Carrier

MAN	Metropolitan Area Network
PDU	Protocol Data Unit
PMD	Physical Medium Dependent
QOS	Quality of Service
SAR	Segmentation and Reassembly
SDH	Synchronous Digital Hierarchy
SDU	Service Data Unit
SIMNET	Simulation Networking R & D Project
SMTP	Simple Mail Transfer Protocol
SONET	Synchronous Optical Network
TC	Transmission Convergence
UDP	User Datagram Protocol
WAN	Wide Area Network

LIST OF REFERENCES

[Arm92] Armitage, G. H., Prototyping an ATM Adaption Layer in a Multimedia Terminal, *International Journal of Digital and Analog Communications Systems*, November 24, 1992.

[Amy94] Amy, Robert M., Standards by Consensus, *IEEE Communications Magazine*, January 1994.

[Bae91] Bae, Jaime Jungok, Tatsuya Suda, Survey of Traffic Control Schemes and Protocols in ATM Networks, *Proceedings of the IEEE*, February 1991.

[Blumen92] Blumenthal, Steven, Future Trends in Networking Technology for Distributed Simulation, Presentation, *BBN Systems and Technology*, July 31, 1992.

[Cavan92] Cavanaugh, John D., and Timothy J. Salo, Internetworking with ATM WANs, *Minnesota Supercomputer Center, Inc.*, December 14, 1992.

[Chung92] Chung, James W., An Assessment and Forecast of Commercial Enabling Technologies for Advanced Distributive Simulation, Interim Working Draft, October 29, 1992.

[DePry93] Deprycker, M., *Asynchronous Transfer Mode, Solution for Broadband ISDN*, 2nd ed., 1993.

[Doris92] Doris, Ken, Issues Related to Multicast Groups, *Grumman Aerospace and Electronics*, Great River, N.Y., 1992.

[Irv93] Irvin, David J., Making Broadband-ISDN Successful, *IEEE Network*, January 1993.

[ISTA93] Institute for Simulation and Training, *Communication Architecture for Distributive Interactive Simulation (CADIS)*, November 8, 1993.

[ISTB93] Institute for Simulation and Training, *The DIS Vision, A Map to the Future of Distributed Simulation*, Comment Draft, October 1993.

[Klien92] Klienrock, Leonard, The Latency/Bandwidth Tradeoff in Gigabit Networks, *IEEE Communications Magazine*, April 1992.

[Kor92] Korzenioski, Paul, ATM: The Next Wave?, *RS Magazine*, December 1992.

[Maced94] Macedonia, Michael, *A Network Software Architecture for Large Scale Virtual Worlds*, Draft, Naval Postgraduate School, Monterey CA., 1994.

[Maced93] Macedonia, Michael, *IP Multicast in DIS: Implementation with NPSNET-IV*, Presentation, Naval Postgraduate School, Monterey CA., 1993.

[Masn94] Masnavi, A., *Joint Computer-aided Acquisition and Logistics System and ATM*, Presentation, Naval Post Graduate School, Monterey, CA., Febuary 1994.

[Maz93] Mazda, F., *Telecommunications Engineer's Reference Book*, 1993.

[Min93] Minolta, D., *Enterprise Networking, Fractional T1 to SONET, Frame Relay to BISDN*, 1993.

[New92] Newman, Peter, ATM Technology for Corporate Networks, *IEEE Communications Magazine*, April 1992.

[NRL94] Naval Research Laboratory, *NRL's ATM Testbed and Fiber Grid*, January 21, 1994.

[NRL93] Naval Research Laboratory, *NRL ATM Day*, August 4, 1993.

[Pes93] Peschi, R., M. Deprycker, and T. Van Landegem, *B-ISDN and the OSI Protocol Reference Model*, *IEEE Network*, March 1993.

[Rans93] Ransom M. N., and Dan R. Spears, Application of Public Gigabit Networks, *IEEE Network*, March 1992.

[SRI90] SRI International, *ATD-1 Architecture White Paper*, Edit Draft, 1990.

[Stal92] Stallings, W., *ISDN and Broadband ISDN*, 2nd ed., 1992.

[Wei92] Wei, Liming, FongChong Liaw, Deborah Estrin, Allyn Romanow, and Tom Lyon, *Analysis of a Resequencer Model for Multicast over ATM Networks*, November 1992.

[Wolf91] Wolf, S., R. F. Kubichek, C. R. South, R. A. Schaphorst, and S. D. Voran, How Will We Rate Telecommunications System Performance?, *IEEE Communications Magazine*, October 1991.

[Yam93] Yamamoto, Yutaka, Error Performance in Evolving Digital Networks Including ISDNs, *IEEE Communications Magazine*, April 1989.

[Zhong93] Zhong, Wen De, Yoshikuni Onozato, and Jaidev Kaniyil, A Copy Network with Shared Buffers for Large-Scale Multicast ATM Switching, *IEEE/ACM Transactions On Networking*, April 1993.

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53570 Silvergate Ave
San Diego, California 92152-5246

Margaret Loper 1
UCF/IST
3280 Progress Drive
Orlando, Florida 32826